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NENE FREE JET FACILITY DEVELOPMENT - 1/4 SCALE MODEL TESTS.(U)
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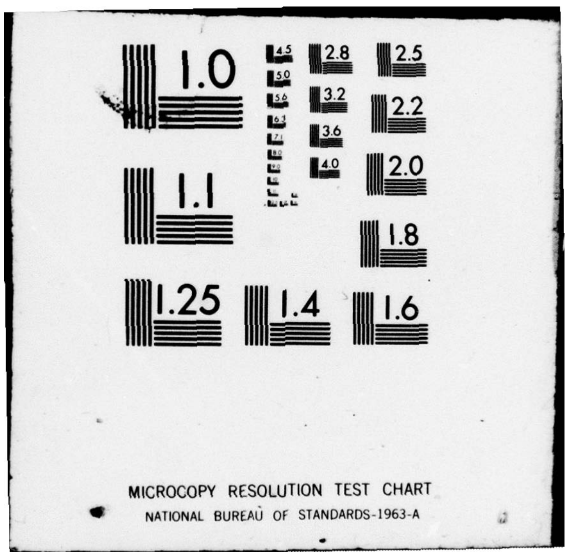
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MELBOURNE, VICTORIA

Mechanical Engineering Technical Memorandum 394

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A.P. COX

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6 NENE FREE JET FACILITY DEVELOPMENT - 1/4 SCALE MODEL TESTS

~~by~~

10 A.P. COX

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SUMMARY

Modifications are in hand to upgrade the existing Nene Free Jet Facility at A.R.L. and these include the provision of a new settling chamber, inlet diffuser, contraction, and final nozzle. The publication describes quarter scale model tests of these components to assess their aerodynamic performance and to ensure, by appropriate modifications where necessary, that full scale performance will be satisfactory.

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CONTENTS

1. INTRODUCTION

Modifications are in hand to upgrade the existing Nene Free Jet Facility at A.R.L.. This is being accomplished by relocating the nozzle outlet to a position which will eliminate a number of the bends in the air supply duct, permit improved access for test equipment, allow a settling chamber to be installed upstream of the final nozzle and a control room to be provided in close proximity to the test area. Improvements are also being made to the air flow control system, to the blow off silencing system and to the quality of air delivered to the Mach 1.6 Propulsion Tunnel which shares the same basic air supply system.

A one quarter scale model of the settling chamber, inlet diffuser, contraction and final nozzle has been made and tested to assess the aerodynamic performance of the design and to ensure that it is satisfactory before undertaking manufacture of the full scale facility.

2. GENERAL DESCRIPTION OF THE PROPOSED FACILITY

Fig. 1 shows a plan view of the compressor, duct, and settling chamber arrangement proposed and Fig. 2 (drawn for the model scale) shows details of the latter. Air delivered from the existing electrically driven, cropped Rolls Royce "Nene" compressor passes through about 14 metres of 0.6 metre inside diameter duct containing three vaned elbows before entering a 10 metre long straight section of 0.6 metre inside diameter duct. Air then enters an initial conical diffusing section of 5 deg. included angle, 9 metres long, expanding to an inside diameter of 1.38 metres. To meet space limitations, a 40 deg. included angle conical diffuser is then employed to expand to the settling chamber diameter of 2.5 metres. To assist diffusion at this wide angle a spherically shaped gauze screen is positioned at entry to the section and a flat gauze screen at exit.

Air then enters the 2.5 metre diameter settling chamber in which a honeycomb of more than 8000 hexagonal cells, each nominally 50 mm across the flats by 435 mm long, is positioned 0.56 metres downstream of the settling chamber inlet. This is followed by four gauze screens spaced at intervals of 0.3 metres.

Air then enters the contraction which has a profile of circular arc shape, continuing to a 45 deg. tangent line. A flange is fitted at this line to permit the attachment of a series of interchangeable nozzles of 0.4, 0.5, 0.7, 1.0 m outlet diameters, thus permitting operation of the facility over a wide range of outlet velocities.

3. DESCRIPTION OF MODEL

A one quarter scale model of the settling chamber, together with its associated diffuser, contraction and outlet nozzle was manufactured and assembled ready for testing. Fig. 2 is a diagrammatic sketch of the model and Fig. 3 a photographic view.

The cylindrical inlet duct and the 5 deg. conical diffuser have been made in flanged sheetmetal sections. The settling chamber is also made of a number of short sheetmetal sections, flanged to permit gauze screens to be supported by clamping between flanges and to be readily removed or changed if necessary. The 40 deg. diffuser is made of wood and fibreglass with a perspex window insert to permit flow visualization experiments. The wooden flange at entry to this diffuser is made in two pieces with the joining surfaces machined at the correct angle to clamp and support the spherically shaped inlet screen. This screen and that at the diffuser exit flange were initially of 10 mesh, 22 S.W.G. wire gauze. The resistance coefficient of each screen in the model was kept the same as that of its full size counterpart by using gauze of the same mesh and wire size.

The honeycomb was made from readily available "Dufaylite" cardboard structural honeycomb having hexagonal cells measuring 20 mm across the flats. Although relatively coarser than the full scale version (and hence likely to give somewhat pessimistic results), this was the closest size of honeycomb material readily available for the model. The cell length to diameter ratio of 8 employed in the full scale honeycomb was maintained by making the model honeycomb 160 mm long. It was supported in a wooden box and mounted between flanged sheetmetal sections in the settling chamber, 150 mm downstream of the screen at exit of the 40 deg. diffuser. Four additional 10 mesh by 22 S.W.G. wire gauze screens were mounted at 75 mm intervals downstream of the honeycomb.

Two alternative contraction sections were made in fibreglass with perspex window inserts to permit flow visualization experiments, Fig. 4. Both were of circular arc contour, one (Fig. 4a) being of spherical shape and the other (Fig. 4b) with a greater radius of curvature. Although the latter might be expected to perform better, the former was tested first because the construction cost of the full scale version promised to be substantially lower. Two nozzles of 250 mm and 150 mm outlet diameter (corresponding to 1000 mm and 600 mm full scale) were made in fibreglass to the design shown in Fig. 5. This figure also shows details of a sheetmetal nozzle which could be attached to the 150 mm nozzle outlet to reduce the outlet further to 95 mm diameter (corresponding to 380 mm full size).

The model was connected to the outlet of a Richardson "VB4" fan with a 20 mesh, 28 S.W.G. wire gauze screen at inlet to the 150 mm cylindrical duct to remove flow distortions emanating from a bend at the fan delivery pipe. Air flow through the model was controlled by a throttle valve on the inlet side of the fan.

4. METHOD OF TEST

4.1 Pressure Measurement

Pitot static traverses were made in the vertical and horizontal planes at the five stations shown in Fig. 2. In the settling chamber an additional section of duct (0.1 m long) was inserted at the traversing station to accommodate the pitot static probe when necessary. From these measurements values of velocity were calculated using standard values of atmospheric pressure and temperature, and were then plotted against traverse position for

each station. Reynolds number of these tests based on settling chamber diameter was 120,000.

4.2 Flow Visualization by Smoke

Smoke was used in an attempt to discover if any separated regions of airflow existed in the model, particularly in the wide angle diffuser and the contraction. Smoke supplied by a small smoke generator was fed through tubing to a probe inserted in the duct with its end bent to face downstream so that smoke leaving the probe would have a similar velocity and direction to the airflow at that point. Tests were carried out at nozzle outlet velocities of less than 1 metre/sec..

4.3 Flow Visualization by Tuft

A tuft mounted on the end of a wand was also used to explore areas in the diffuser and contraction. The wand was inserted through small holes in the side of the duct and the behaviour of the tuft observed through the perspex windows. These tests were conducted over a range of velocities.

5. RESULTS AND DISCUSSION

5.1 General

The results of pitot-static traverses made in the horizontal and vertical planes at each of the Stations 1, 2, 3, 4 and 5 of Fig. 2, revealed that the distribution in the vertical and horizontal planes at each station was closely similar and symmetrical about the duct axis. Distribution curves for the horizontal plane only are therefore presented in Fig. 6 and these should be examined in relation to the diagram of the model, Fig. 2.

Velocity distribution at entry to the 5 deg. conical diffuser, Station 1, is typical of pipe flow, and is representative of the distribution presently existing in the full scale duct (Ref. 1). The distribution curve at exit to the 5 deg. diffuser, Station 2, has a symmetrical peak in velocity centred on the duct axis, and indicates that the flow in the diffuser is attached and that the diffuser is performing reasonably. The distribution curve at exit of the 40 deg. wide angle diffuser, Station 3 is also symmetrical, having a central peak on the duct axis, indicating that the combination of wide angle diffuser and inlet and outlet screens is satisfactory. The velocity distribution at the settling chamber exit, Station 4 is quite uniform, indicating that the settling chamber screens are effective in producing a good distribution at entry to the contraction.

The outlet nozzle velocity distribution was initially measured 0.6 nozzle diameters downstream of the nozzle exit plane for the 250 and 150 mm diameter nozzles, and 0.2 diameters downstream for the 95 mm nozzle. These curves revealed that the velocity distribution was uniform to within 1% over 90% of the nozzle outlet area.

Although the results so far described were generally satisfactory, more detailed investigations of each component were undertaken as described below in order to allow some optimisation of the design.

5.2 Spherical Contraction

The flow in the spherical contraction was examined by means of a tuft mounted on a wand. The tuft was inserted through the nozzle opening and the flow in the contraction and nozzle region was explored, particularly on the contraction wall. It was observed that the tuft behaved in a stable manner in these areas.

Smoke was then introduced into the airstream at Station 3 and its behaviour observed through the perspex windows. Despite some eddy formation in the wide angle diffuser, upstream of the settling chamber (to be discussed later), the effect of the honeycomb and screens in the settling chamber was to produce stable filaments of smoke which could be seen to issue from the final screen and follow the streamlines in the contraction to form parallel streamlines in the nozzle outlet jet.

From the above results it was concluded that satisfactory flow existed in the spherical contraction.

5.3 Nozzle

During the smoke tests discussed above, some instability was observed in the jet boundary, commencing at the square edged nozzle lip. Eddies formed adjacent to the lip in the jet induced flow and then broke away in a continuous cyclic fashion, travelling downstream in the jet boundary and gradually dissipating. In order to reduce this eddy shedding process a cylindrical extension, half a nozzle diameter in length with an 0.5 mm radius lip was added to the 250 mm and 150 mm diameter nozzles to provide an unobstructed path for the jet induced flow. Fig. 7 shows details of this modification.

The test with smoke was then repeated and it was observed that the cyclic eddy formation and shedding process was no longer present. Velocity traverses in the horizontal plane at Station 5 were then repeated for the extended 250 mm and 150 mm nozzles. Because of the nozzle extensions the traversing plane was now only 30 mm downstream of the nozzle exit plane in each case. The distribution curves were again plotted and revealed that the flow was of the same degree of uniformity as found initially.

5.4 Wide Angle Diffuser

5.4.1 Original behaviour

A closer examination of the flow in the wide angle diffuser was made by traversing a small pitot-static probe up to 200 mm inwards from the diffuser wall towards the duct axis at three points, 50, 170 and 290 mm downstream of the diffuser inlet screen (Fig. 8). The probe was mounted on a pivot to permit alignment with the local flow direction. The velocity distribution curves obtained are shown plotted in Fig. 9. The curves indicate that a region of separated flow exists at the diffuser wall, commencing upstream of the 170 mm station and increasing in size with distance downstream.

Flow visualization using smoke injected just upstream of the diffuser inlet screen was tried to examine the flow behaviour but this gave

inconclusive results, possibly because of the turbulent nature of the flow in this region. The flow close to the diffuser wall was explored further with a tuft, mounted on a wand and inserted through the probe access holes in the diffuser wall; the tuft behaved in an unstable manner in the regions indicated as separated by the pitot-static traverses, confirming the existence of a separated region.

5.4.2 Diffuser modifications

To improve the flow in the wide angle diffuser, the following modifications were made and tested:-

1. A 10 mesh gauze screen was inserted at the mid-length of the 5 deg. diffuser.

2. A high resistance, 20 mesh screen was substituted for the 10 mesh screen at inlet to the wide angle diffuser.

3. Modifications 1 and 2 above were made in combination.

4. A high resistance, 20 mesh screen was substituted for the 10 mesh screen at the wide angle diffuser exit plane, and tested in combination with the high resistance screen at entry, (Modification 2).

5.4.3 Test results

Modification 1.

The 10 mesh screen at the midlength of the 5 deg. diffuser was aimed at improving velocity distribution at entry to the wide angle diffuser, and hence the flow in the diffuser itself.

The velocity traverse at station 2 was repeated and the distribution curve when plotted showed that the screen had produced a smoother distribution of the same general shape observed before. However repeat traverses near the wall of the wide angle diffuser showed that the separated region remained unchanged.

Modification 2.

The screen at the midlength of the 5 deg. diffuser was removed, and a higher resistance screen of 20 mesh gauze was substituted for the 10 mesh screen at entry to the wide angle diffuser. Velocity traverses were repeated at each of the three stations along the diffuser wall and the velocity distribution curves obtained are shown plotted in Fig. 10. It will be seen that each curve has moved towards the left, in particular the curve for the 170 mm station indicates that the flow is now attached at that station.

Modification 3.

To further check the effect of the 10 mesh screen at mid-length of the 5 deg. diffuser, it was again installed in the duct and the traverses in the wide angle diffuser repeated with the high resistance diffuser entry screen also in place. The distribution curves obtained were found to be the same as

those found for the original configuration, the improvement due to the high resistance screen at entry to the wide angle diffuser having been lost.

Modification 4.

For this modification, a high resistance, 20 mesh screen was installed in place of the 10 mesh screen at the wide angle diffuser exit plane and tests were made with the high resistance entry screen also in place. A velocity traverse was again made at the 290 mm station and the distribution curve obtained is shown plotted in Fig. 11 together with the curves previously obtained for this station for comparison. The curve indicates that the flow is now attached to the wall at the 290 mm station.

The test with smoke was then repeated but again failed to clearly indicate the nature of the flow.

The flow near the wall of the diffuser was again explored with a tuft as before. The tuft behaved in a stable manner in all regions of the diffuser, confirming that the flow at the diffuser wall was attached.

5.5 Non-Spherical Contraction

As mentioned earlier, a contraction design having a profile based on a circular arc of 1750 mm radius (full scale) was initially proposed for the facility, but its testing was deferred in favour of a design based on a spherical profile which held the promise of substantially lower construction cost in the full scale version. The design profile of each quarter scale model contraction is given in Fig. 4.

As the non-spherical contraction was now available it was installed in place of the spherical contraction and tested in conjunction with the 250 mm outlet nozzle to provide a basis for comparison with the spherical contraction.

A velocity traverse was again made at Station 5, 30 mm downstream of the nozzle exit plane as before and the distribution curve plotted.

The curves for both contractions are compared in Fig. 12. It will be seen that the spherical contraction produces a velocity distribution which is uniform to within 0.5% over the central 80% of the nozzle outlet area compared with the non-spherical contraction which is uniform to within 0.8% over the same area.

A flow visualization test using smoke introduced upstream of the wide angle diffuser was made and produced results identical to that for the spherical contraction, with stable filaments of smoke following the streamlines through the contraction and emerging in parallel lines in the outlet jet.

The flow in the contraction was further explored, particularly the regions near the wall, using a tuft as before. The tuft behaved in a stable manner in all regions.

6. CONCLUSIONS

Modifications to the original design of the facility have resulted in excellent performance at the model scale. A summary of the modifications made and of their effects is as follows:

1. A thin cylindrical extension to the outlet nozzles was effective in preventing instability in the mixing region between the jet and the jet induced flow.

2. A 10 mesh gauze screen at mid-length of the 5 deg. diffuser was found to have an adverse effect on the flow in the wide angle diffuser.

3. High resistance screens at entry and exit of the wide angle diffuser are effective in stabilizing the flow in the diffuser.

4. The settling chamber as designed is adequate to produce a uniform flow distribution at entry to the contraction.

5. The spherically profiled contraction produces a velocity distribution at the outlet uniform to within 0.5% over 80% of the jet area, compared with 0.8% for the non-spherical profile, and offers substantial savings in construction cost.

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COX, A.P.	The A.R.L. Supersonic PropulsionTunnel Investigation of Losses in Air Supply Ducting. A.R.L. Technical Memorandum M.E.312,1968.

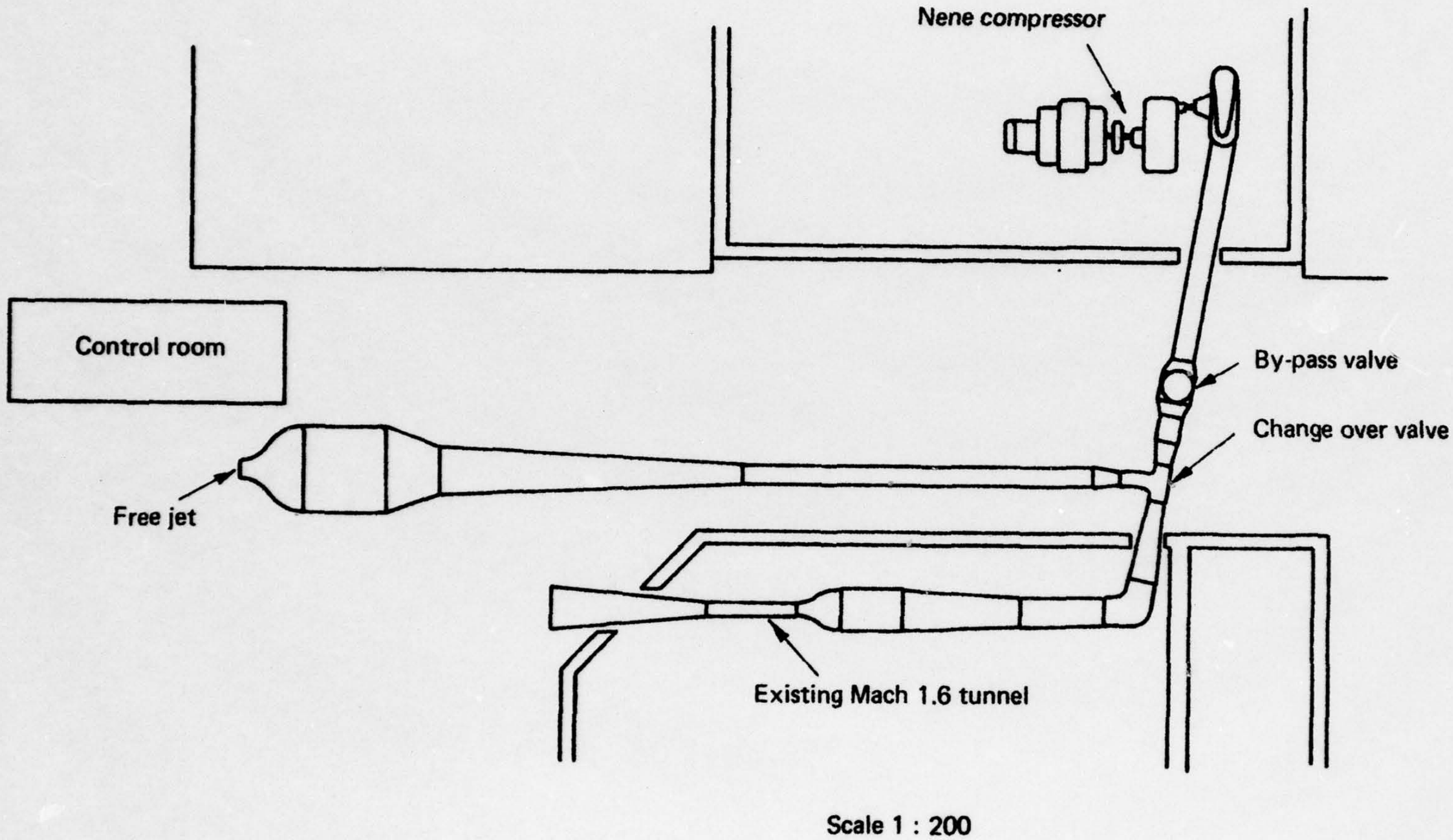

FIG. 1. GENERAL ARRANGEMENT, NENE FREE JET FACILITY

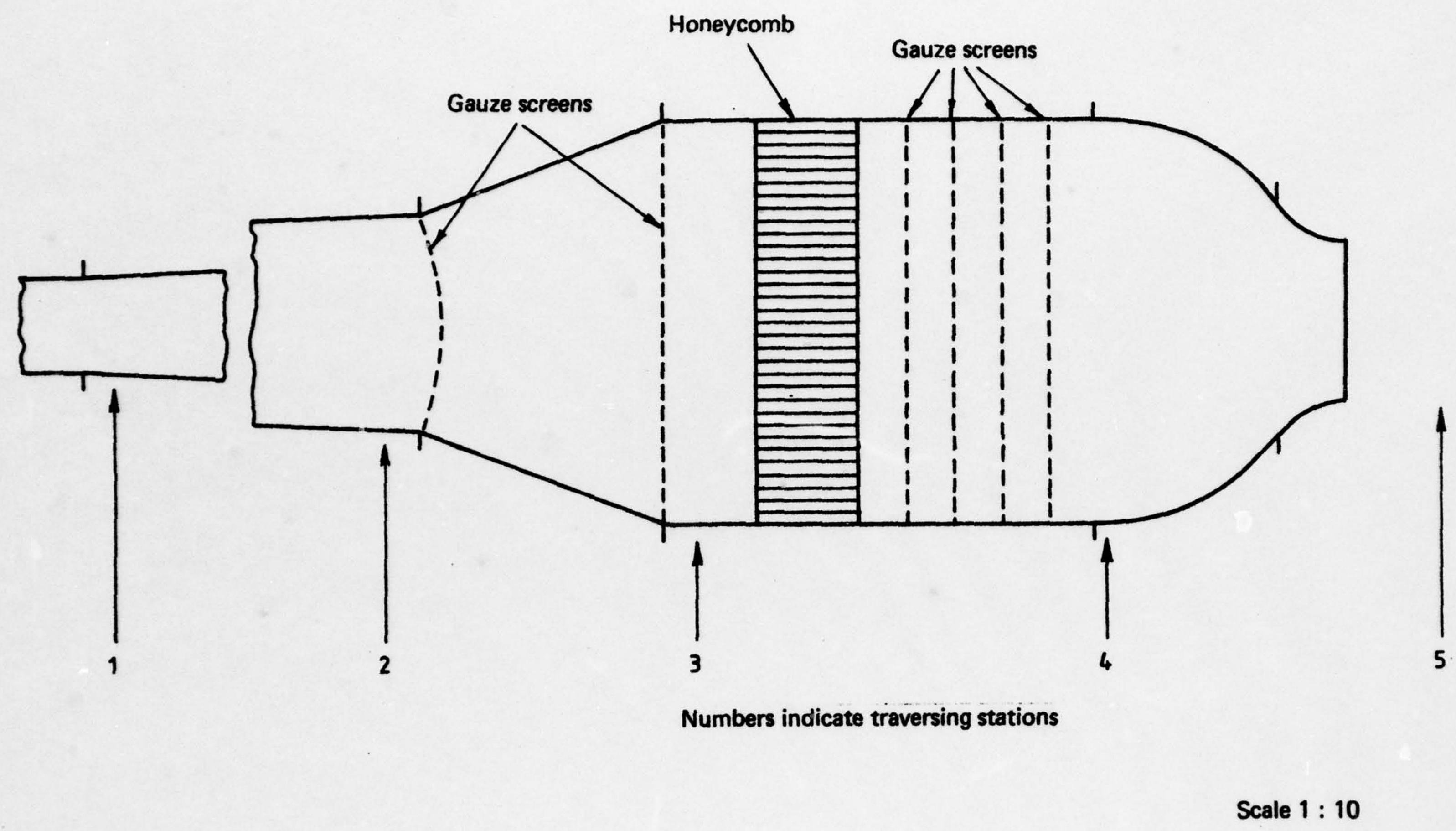

FIG. 2. MODEL SETTLING CHAMBER

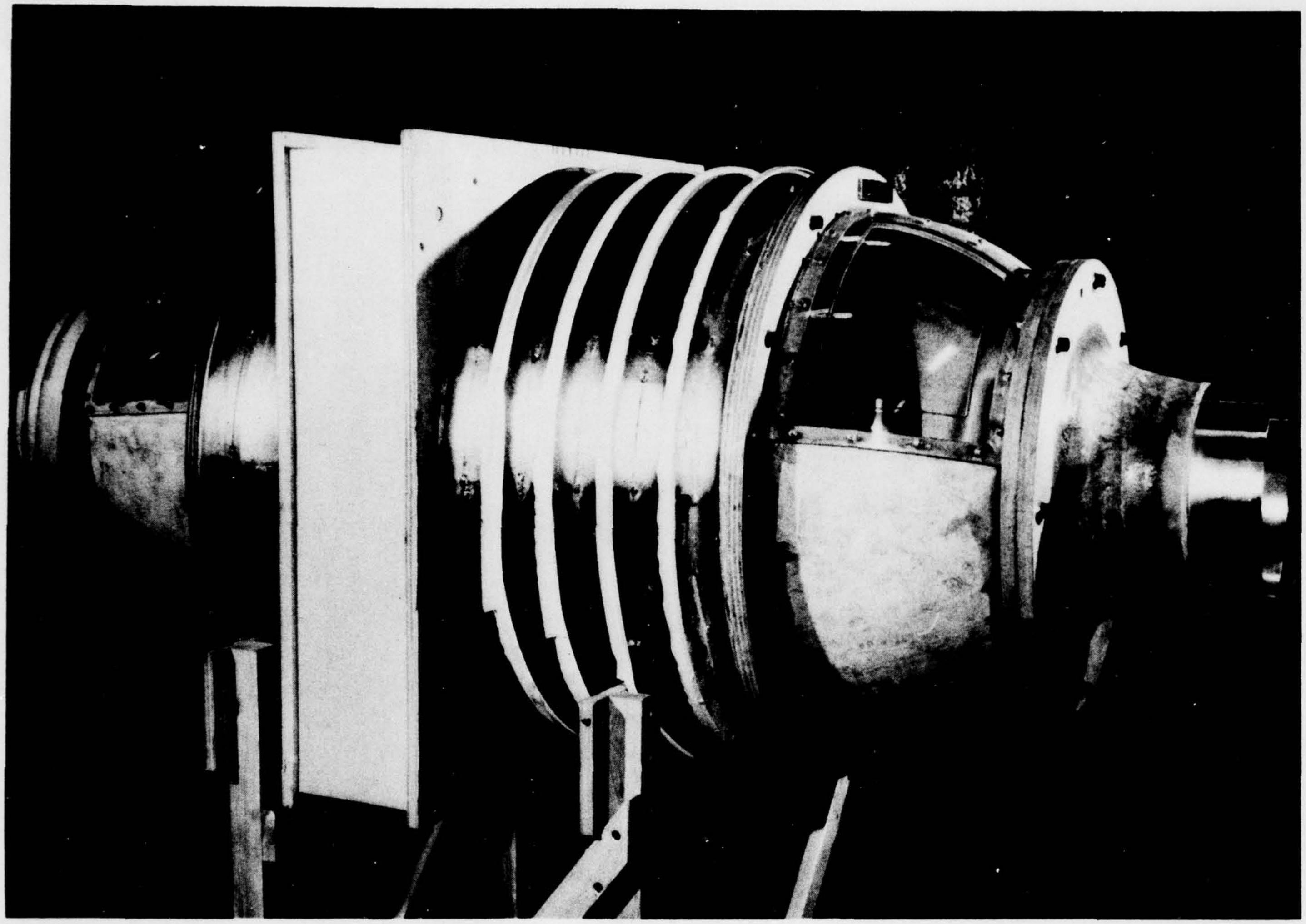

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FIG. 3. MODEL SETTLING CHAMBER

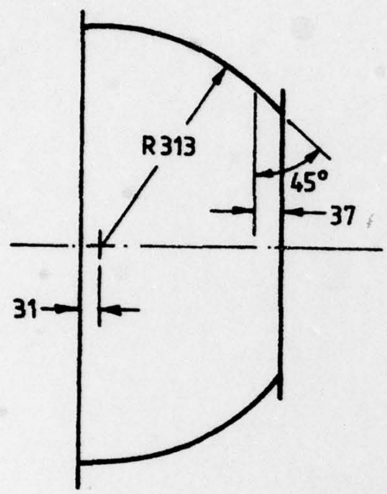


Fig. 4a

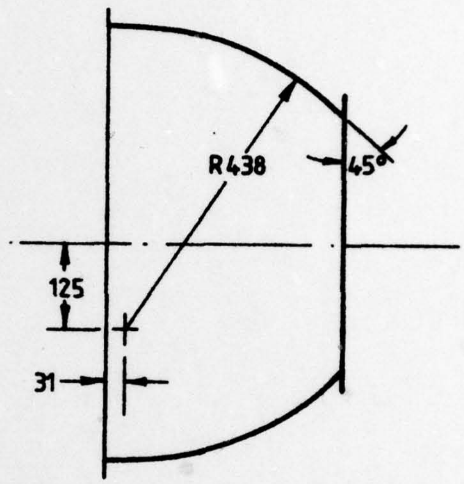
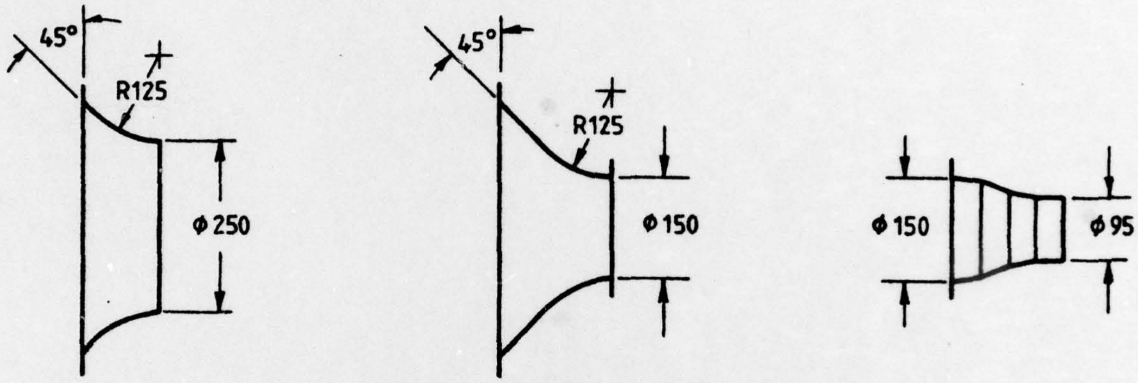


Fig. 4b

Scale 1 : 10

FIG. 4. CONTRACTION CONTOURS



Scale 1 : 10

FIG. 5. OUTLET NOZZLES

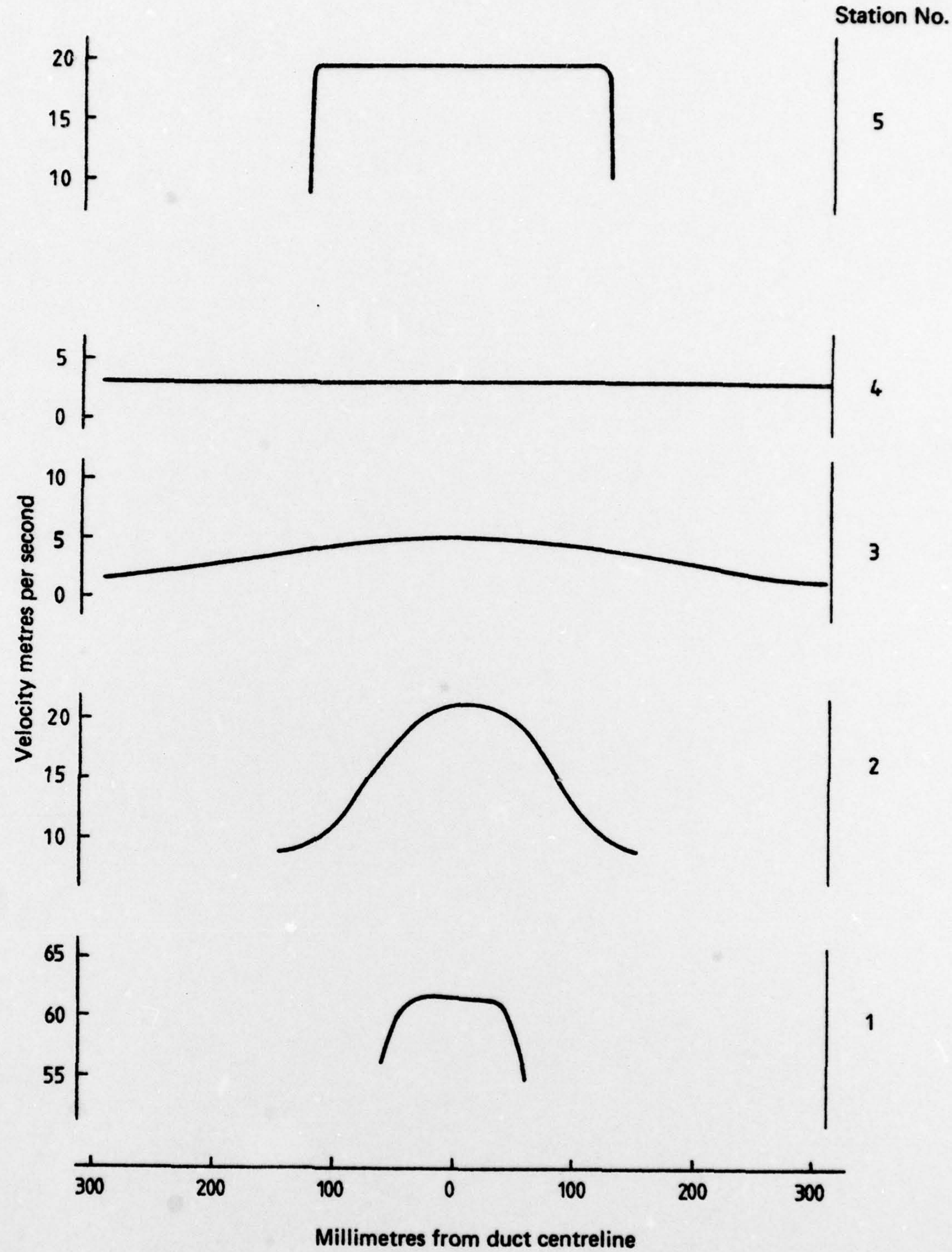


FIG. 6. VELOCITY PROFILES, MODEL SETTLING CHAMBER

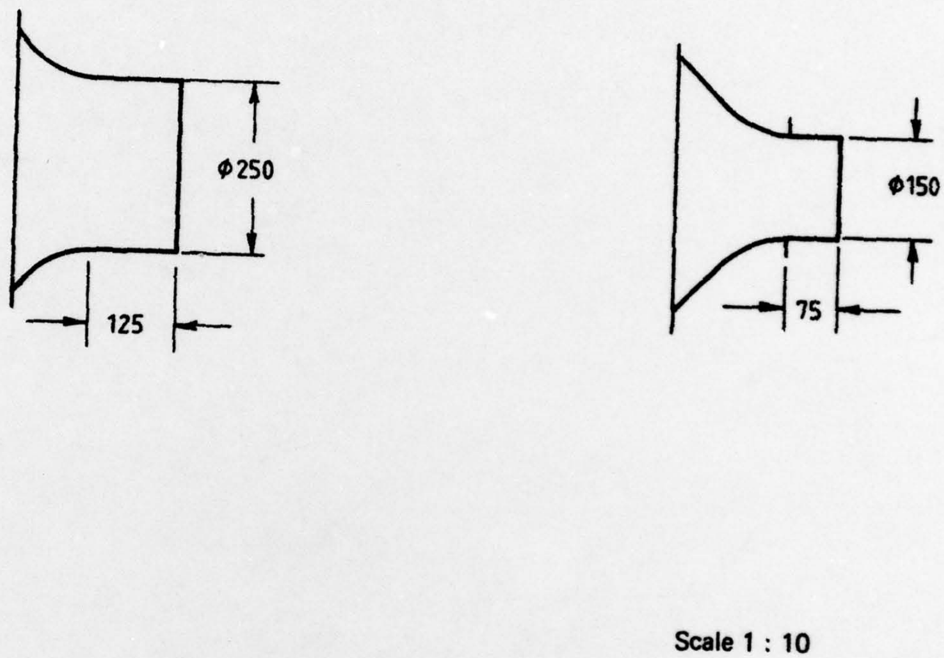


FIG. 7. MODIFIED NOZZLES

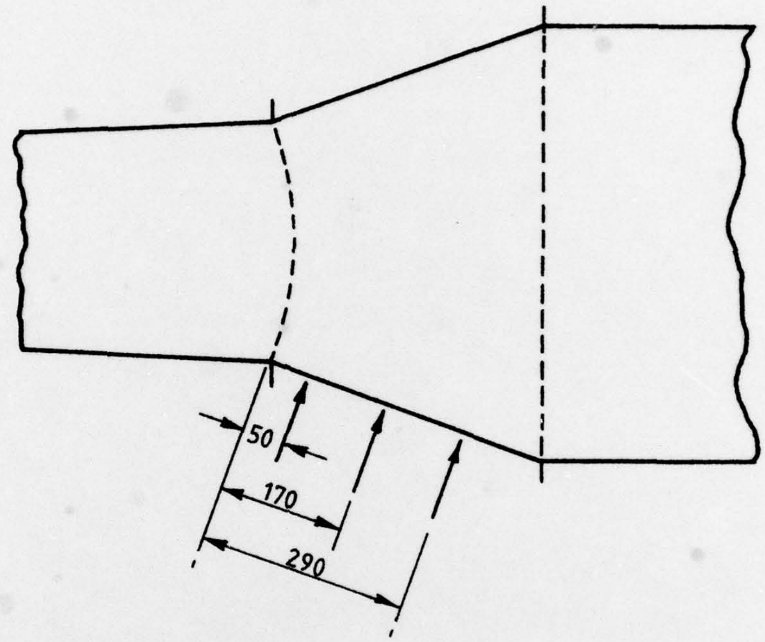


FIG. 8. WIDE ANGLE DIFFUSER TRAVERSING STATIONS

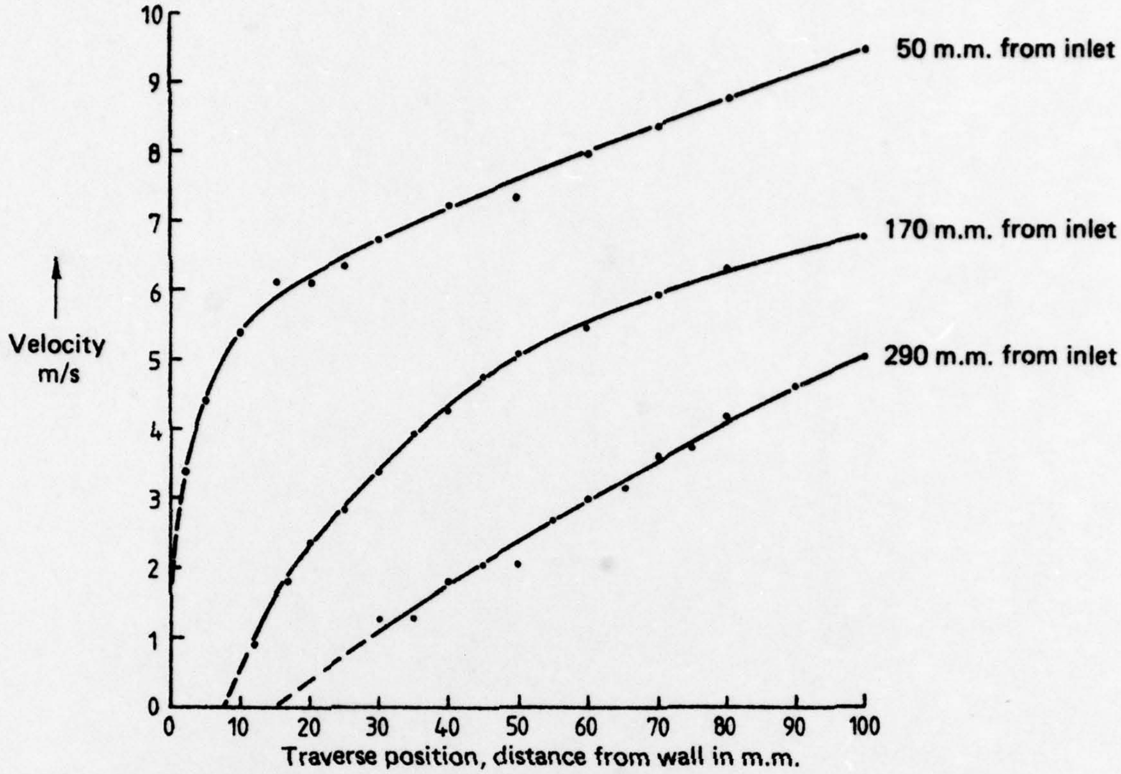


FIG. 9. WIDE ANGLE DIFFUSER, VELOCITY DISTRIBUTIONS NEAR WALL PRIOR TO MODIFICATION

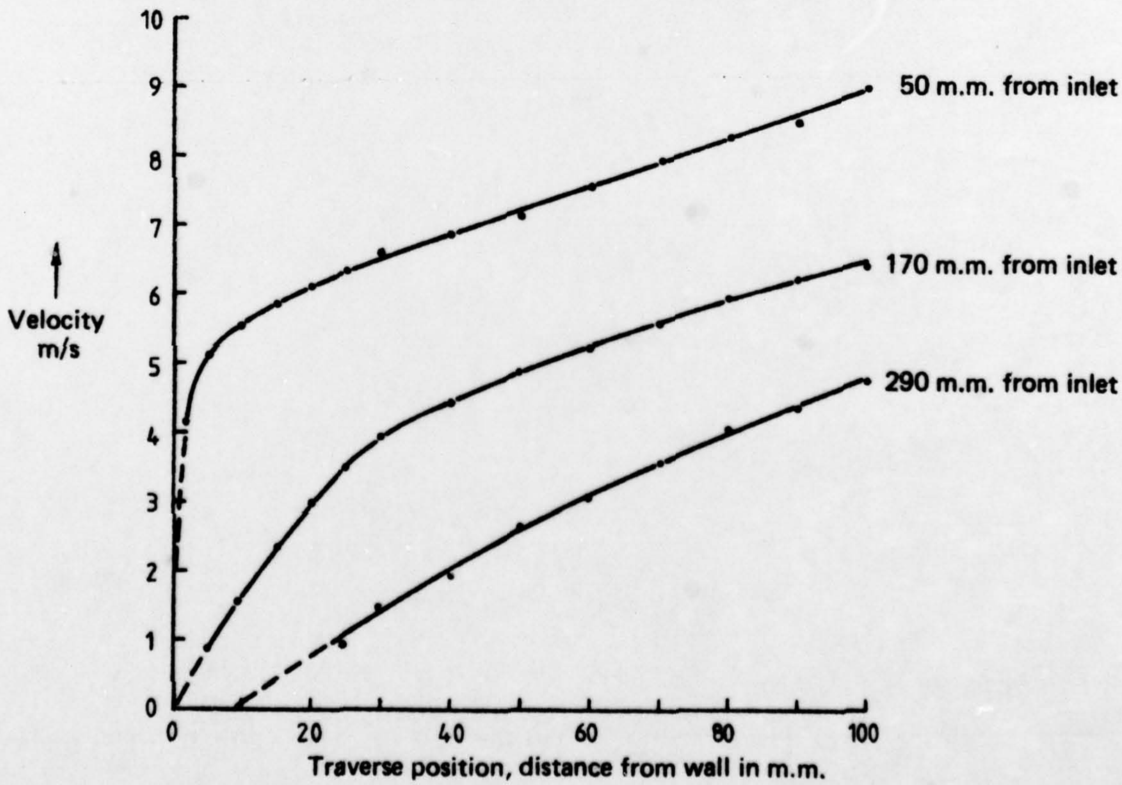


FIG. 10. WIDE ANGLE DIFFUSER, VELOCITY DISTRIBUTION NEAR WALL WITH HIGH RESISTANCE SCREEN AT INLET

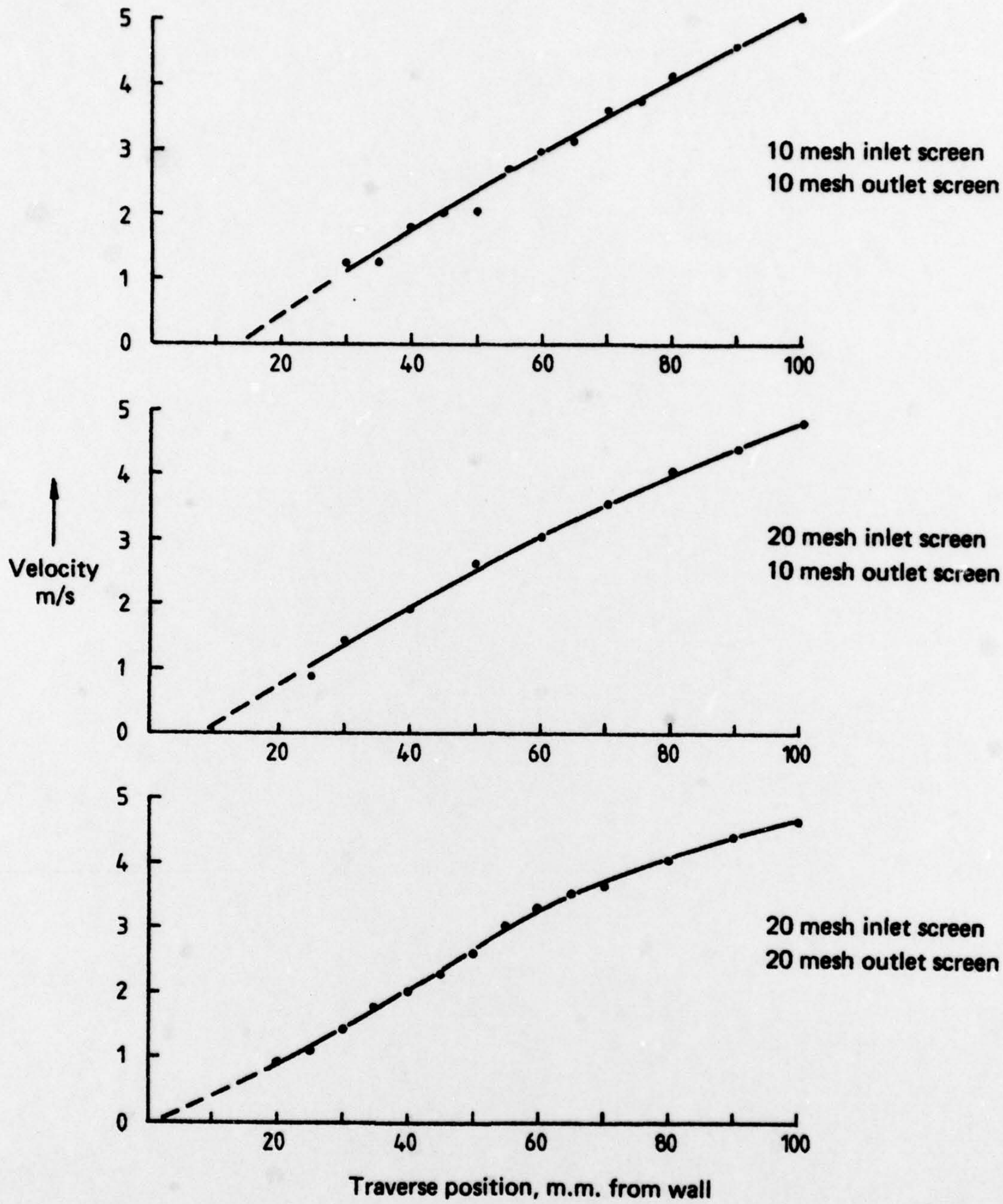


FIG. 11. WIDE ANGLE DIFFUSER, VELOCITY DISTRIBUTION NEAR WALL, 290mm DOWNSTREAM OF INLET SCREEN

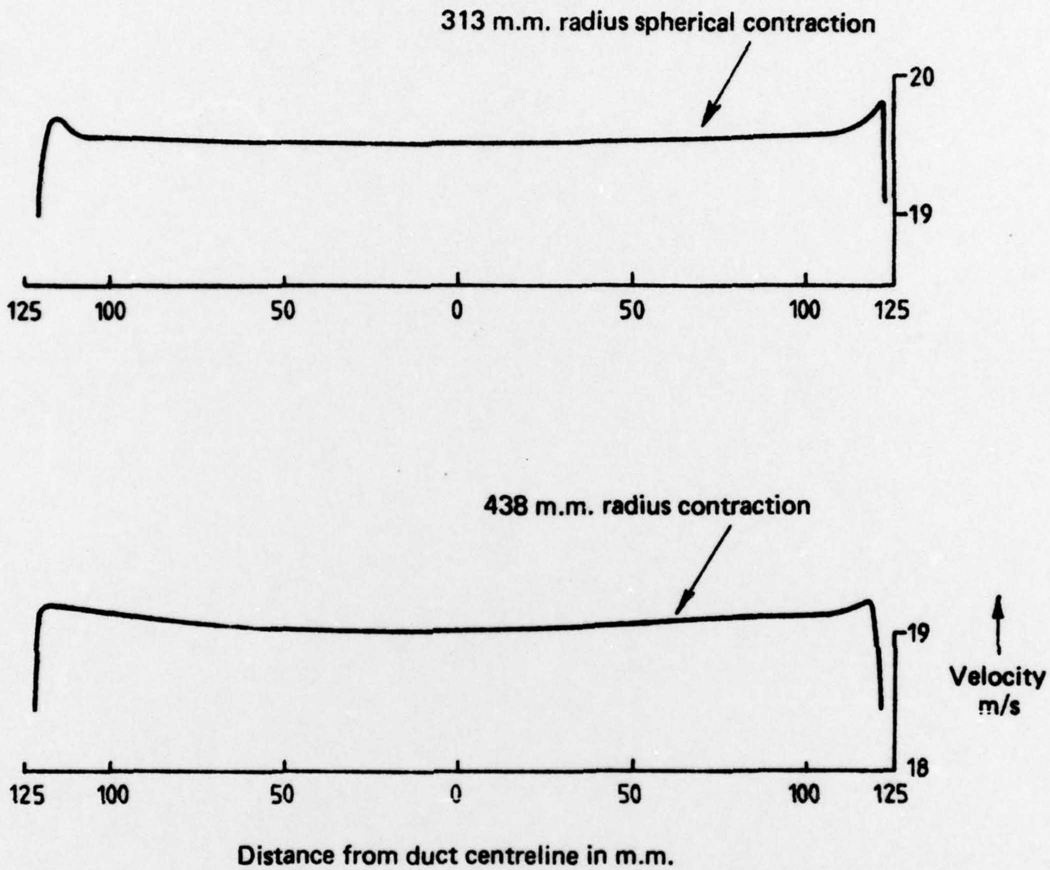


FIG. 12. EFFECT OF CONTRACTION RADIUS ON OUTLET VELOCITY PROFILE

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16. ABSTRACT

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